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Passive standoff detection of SF_6 plumes at 500 meters

Measurement campaign to support the evaluation of Telops imaging spectrometer (FIRST)

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14. ABSTRACT
This note reports the results of a data collection campaign performed with the CATSI sensor to measure the detectability, identification and column density of a SF6 plume. The measurements were made simultaneously with the Telops imaging sensor known as FIRST. The objective of this measurement campaign was to provide a validation of the Telops FIRST spectrometer. Measurements were taken at the 500 m open-air corridor at DRDC Valcartier on September 29, 2004.

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Abstract

This external client report summarizes the results of a data collection campaign performed with the CATSI sensor to measure the detectability, identification and column density of a SF_6 plume. The measurements were made simultaneously with an imaging sensor known as FIRST, which was developed by Telops Inc. The objective of this measurement campaign was to provide an evaluation of the Telops FIRST spectrometer. Measurements were made at the 500 m open-air corridor at DRDC Valcartier on September 29, 2004.

Résumé

Ce rapport pour un client externe rapporte les mesures effectuées avec CATSI sur la détectabilité, l'identification et la quantification d'un panache de SF6. Les mesures ont été effectuées simultanément avec le spectromètre imageur FIRST de Telops. Ces mesures ont été produites afin d'aider l'évaluation du spectromètre de Telops. Ces mesures ont été effectuées sur le corridor de 500 mètres de RDDC Valcartier le 29 septembre 2004.

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Executive summary

The development of techniques for the passive detection, identification and quantification of chemical vapours is a very active research sector. Telops is currently developing an imaging Fourier-transform infrared spectrometer for this application.

This external client report presents the results of a data collection campaign held on September 29, 2004 at Defence Research and Development Canada (DRDC) – Valcartier. The results consist of the detection, identification and the integrated path-concentrations (ppm-m) of SF_6 plumes using the Compact ATmospheric Sounding Inteferometer (CATSI) and the Telops imaging spectrometer (FIRST).

Lavoie, H., E. Puckrin and J.-M.Thériault. 2005. Passive standoff detection of SF6 plumes at 500 meters, measurement campaign to correlate Telops imaging spectrometer (FIRST). ECR 2004-373. Defence R&D Canada – Valcartier.

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Le développement de techniques pour la détection, l'identification et la quantification en retrait de vapeurs chimiques est un secteur de recherches très actif. Telops développe actuellement un spectromètre imageur infrarouge par transformée de Fourrier pour cette application.

Le présent rapport pour client externe présente les résultats d'une campagne de mesure effectuée le 29 septembre 2004. Les mesures de détection, identification et de quantification fut effectuées sur des panaches d'hexafluorure de souffre situé à une distance d'environ 500m. Ces mesures on été effectuées simultanément avec les spectromètres CATSI de RDDC Valcartier et FIRST de la compagnie Telops.

Lavoie, H., E. Puckrin and J.-M.Thériault. 2005. Passive standoff detection of SF6 plumes at 500 meters, measurement campaign to correlate Telops imaging spectrometer (FIRST). ECR 2004-373. R&D pour la Défense Canada– Valcartier.

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1. Introduction

This external client report (ECR) presents the results of a data collection campaign held on September 29, 2004 at Defence Research and Development Canada (DRDC) – Valcartier. The results consist of the detection, identification and the integrated path-concentrations (ppm-m) of SF_6 plumes using the Compact ATmospheric Sounding Inteferometer (CATSI). These results will serve to support the evaluation of the Telops imaging spectrometer (FIRST).

This report describes the monitoring method with CATSI and the parameters associated with the chemical plume release. This is followed by a summary of the results in graphical form of the spectral radiance, column density (CL) and correlation coefficients (r^2).

2. Material and methods

2.1 Monitoring method

The passive standoff monitoring of chemical vapours with CATSI is based on the differential detection equation derived with the atmospheric parameters defined in Fig. 1. It can be verified[1] that if the cloud occupies a fraction *f* of the field-of-view then the radiance differential would be given by,

$$\delta L_{calc} \equiv L_{gas} - L_{clear} = \Delta L_{clear} + f\left(1-\tau_{gas}\right)\left(B_{gas}\tau_{near} + N_{near} - L_{clear} - \Delta L_{clear}\right). \quad (1)$$

Equation 1 represents a general expression that represents the differential radiance of a cloud having a filling factor (*f*) with a provision for handling a possible background variation (ΔL_{clear}) between the two simultaneously observed scenes. The parameter L_{gas} is the radiance of an atmosphere containing the cloud where B_{gas} and τ_{gas} represent the Planck radiance and transmittance, respectively, associated with the cloud. The expression $(1 - \tau_{gas})$ denotes the cloud spectral emissivity, and N_{near} corresponds to the near-field path radiance. For the general case of a gas mixture composed of i compounds, τ_{gas} is given by,

$$\tau_{gas} = \exp\left[-\sum_i \alpha_i(\nu) C_i L\right], \quad (2)$$

where $\alpha_i(\nu)$ is the spectrally dependent absorption coefficient (1/ppm-m) of compound *i*, C_i is the volume concentration (ppmv) of compound *i*, *L* is the length (m) of the cloud sample, and ν is the wavenumber (cm^{-1}). Note that the quantity of interest, C_iL, is given here in ppm-m.

The basic processing strategy of the detection algorithm[2] (GASEM – GASeous Emission Monitoring) consists of adjusting a set of gas parameters (e.g., *CL* and temperature) to generate a calculated spectrum (δL_{calc}) that best fits the spectral features of the measured spectrum (δL_{meas}) inside a spectral band from ν_{min} to ν_{max}. The minimization equation can be written as,

$$\min \sum_{\nu_{min}}^{\nu_{max}} \left(\delta L_{calc} - \delta L_{meas}\right)^2 . \quad (3)$$

Note that the background radiance drift between the two scenes (ΔL_{clear}) is handled by including a blackbody temperature variation ($\Delta\theta$) in the fitting process. In the current version of GASEM, the radiance differential, δL_{calc}, is calculated using Eq. 2 with $\alpha_i(\nu)$ taken from an IR spectral database. A fast atmospheric transmission/emission model has been integrated into GASEM. This model is a look-up table version of the MODTRAN model[3].

The detection and identification of a given chemical is achieved when the chemical cloud parameters retrieved through a SIMPLEX minimization are physically acceptable, and when a proper correlation factor between the measured spectrum and the spectrum calculated with the best-fit parameters is obtained. The correlation factor (r^2) is defined here as the square of the Pearson's correlation coefficient. It is given by,

$$r^2 = \frac{\left(\sum_{i=1}^{n_{chan}} (x_i - \bar{x})(y_i - \bar{y}) \right)^2}{\sum_{i=1}^{n_{chan}} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n_{chan}} (y_i - \bar{y})^2} \quad , \tag{4}$$

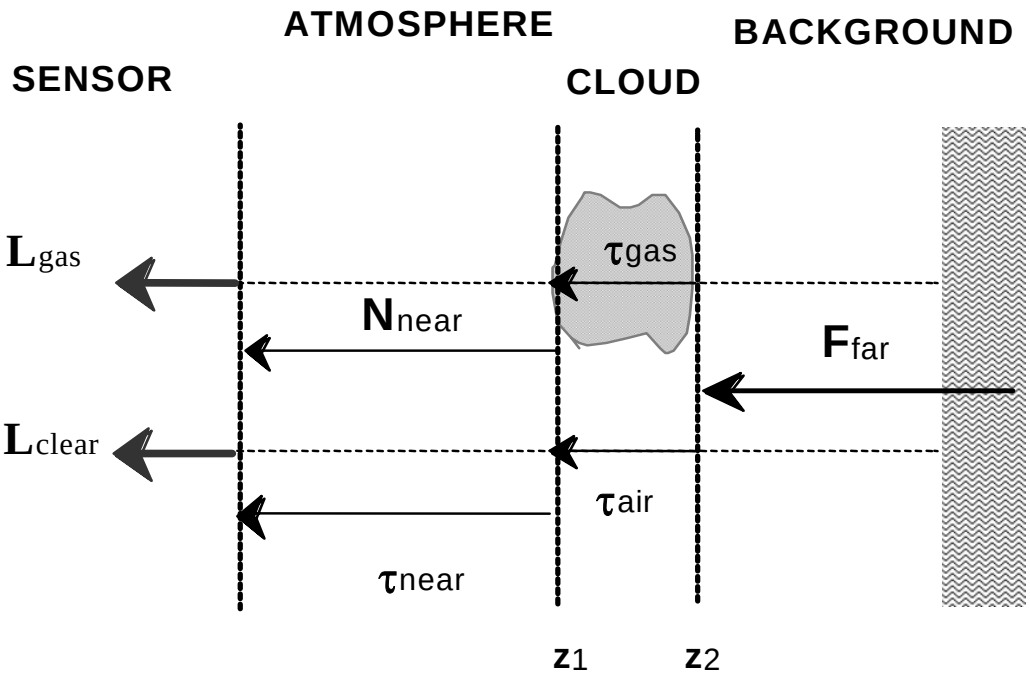


Figure 1. *Diagram and the associated terminology defining the geometry for the differential detection with a dual beam interferometer*

with $x_i \equiv \delta L_{calc}$, $y_i \equiv \delta L_{meas}$, and where n_{chan} represents the number of spectral channels of the chosen band for the spectral fit, x_i is equal to the spectral radiance differential calculated with the best-fit parameters plus the background temperature drift, $\Delta\theta$, and y_i is equal to the measured spectral radiance differential. The terms $\bar{x}$ and $\bar{y}$ represent the average over the spectral band of the calculated and the measured radiance

differentials, respectively. This correlation factor, which varies from no correlation ($r^2 = 0$) to perfect correlation ($r^2 = 1$), is then used to make a decision on the presence or the absence of a given chemical cloud. Figure 1 shows a typical picture of the output screen with the associated parameters generated with the GASEM software during an acquisition at a spectral resolution of 8 cm^{-1}.

2.2 Chemical plume release

In order to obtain a relatively uniform vapour cloud, a stabilized source of SF_6 from a tank was connected to an aluminium pipe with a diameter of 4 cm and a length of 3 m. The pipe was mounted vertically on a tripod at a height of approximately 2 m. The top of the pipe was blocked and a series of 5-mm diameter holes were linearly distributed at 10 cm intervals along the pipe to act as point sources. This arrangement provided an extended linear source of 2 m of vapour as opposed to the point release directly available from the tank outlet. A regulator and flow meter were used to stabilize the SF_6 flow rate at values ranging from 25 to 200 L/min. A stabilized flow rate was maintained for 1 min for each of the measurements.

2.3 Collected temperature

Table 1 presents several useful temperatures measured during the data collection campaign of September 29th. The ambient temperature (T_{amb}) and background temperatures (natural (T_{NAT}), space blanket (T_{SB}) and black shingle (T_{BS})) were recorded for reference and ΔT determination.

Table 1. *Temperature of air (T_{AMB}) and different backgrounds: natural (T_{NAT}), reflective (T_{SB}) and absorbent (T_{BS})*

TIME	T_{AMB}	T_{NAT}	T_{SB}	T_{BS}
	°C	*°C*	*°C*	*°C*
10h35	14.1		-36	34
15h05	18.8	17	-36	50
16h05	19.0	17	-36	41

3. Measurements of SF_6 plumes at 500 meters

The spectral signature of SF_6 is presented in Figure 2. This signature consists of only one band at 947 cm^{-1}.

Figures 3 to 13 summarize the main monitoring results for the spectral radiance, the column density (CL) and the correlation coefficients (r^2). A three-dimensional overlay plot for each single spectrum collected during the SF_6 release was generated for each measurement. The calculations of the integrated path-concentrations and the global r^2, which is a measure of the quality of the fit, are also presented for each gas release. These calculations were made with the GASeous Emission Monitoring (GASEM) algorithm. Each figure is also tagged with the acquisition time associated with the CATSI sensor (time difference between FIRST and CATSI measurements equal 150 s).

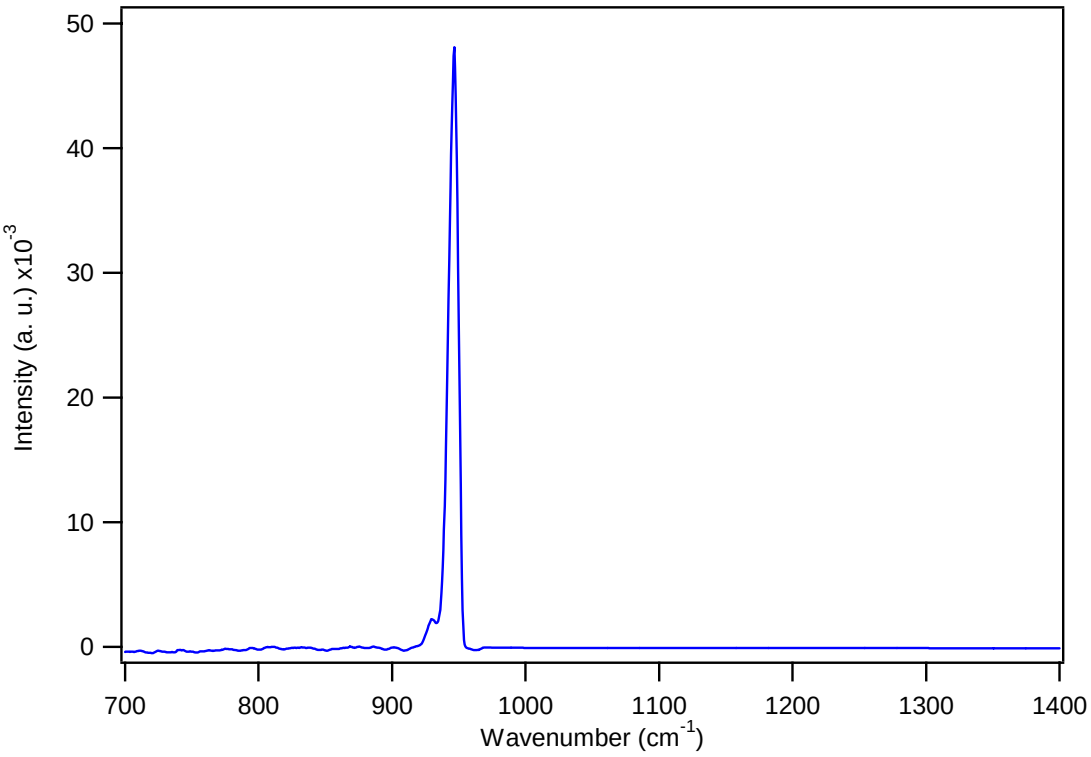


Figure 2. *Spectral signature of SF_6*

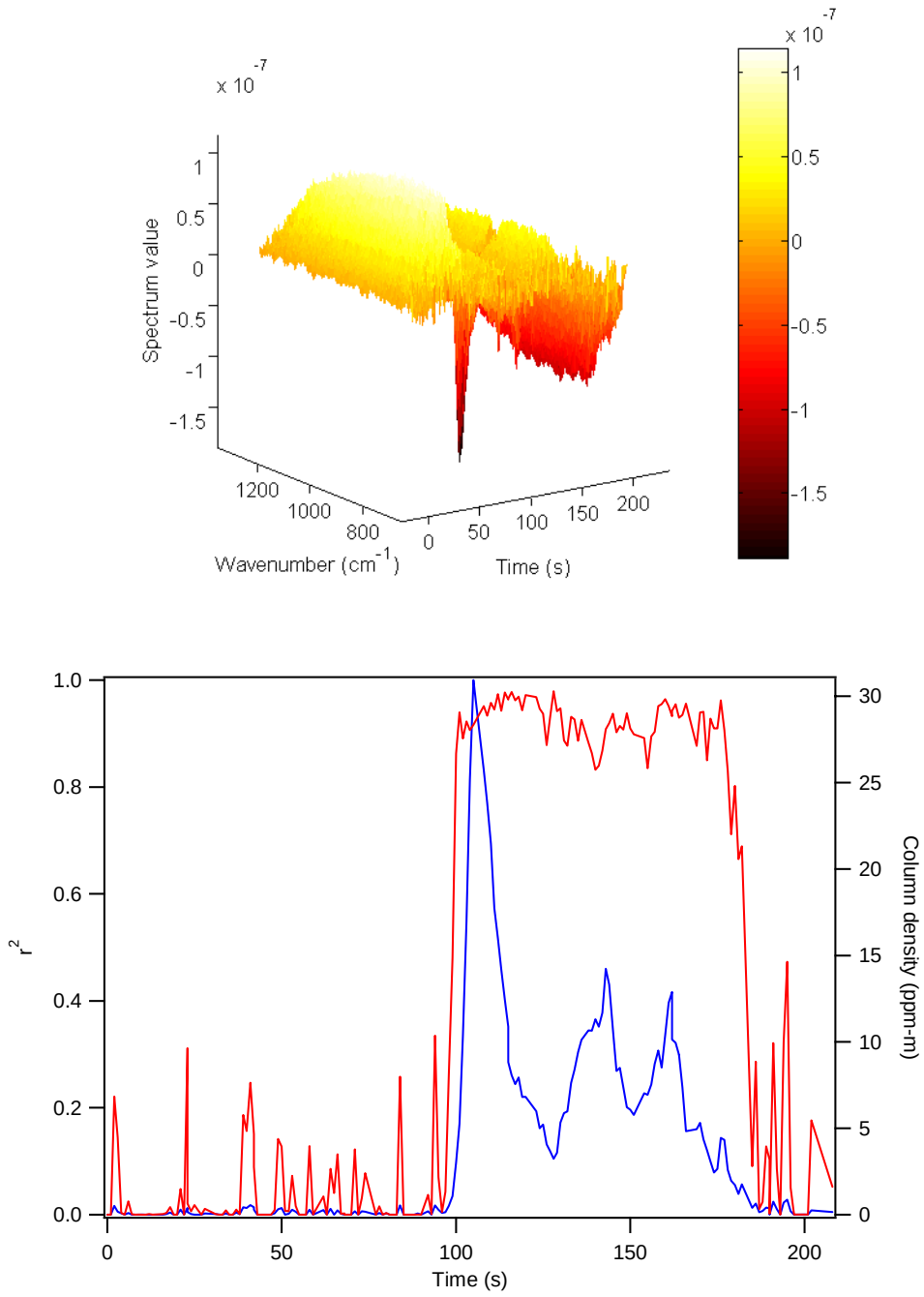
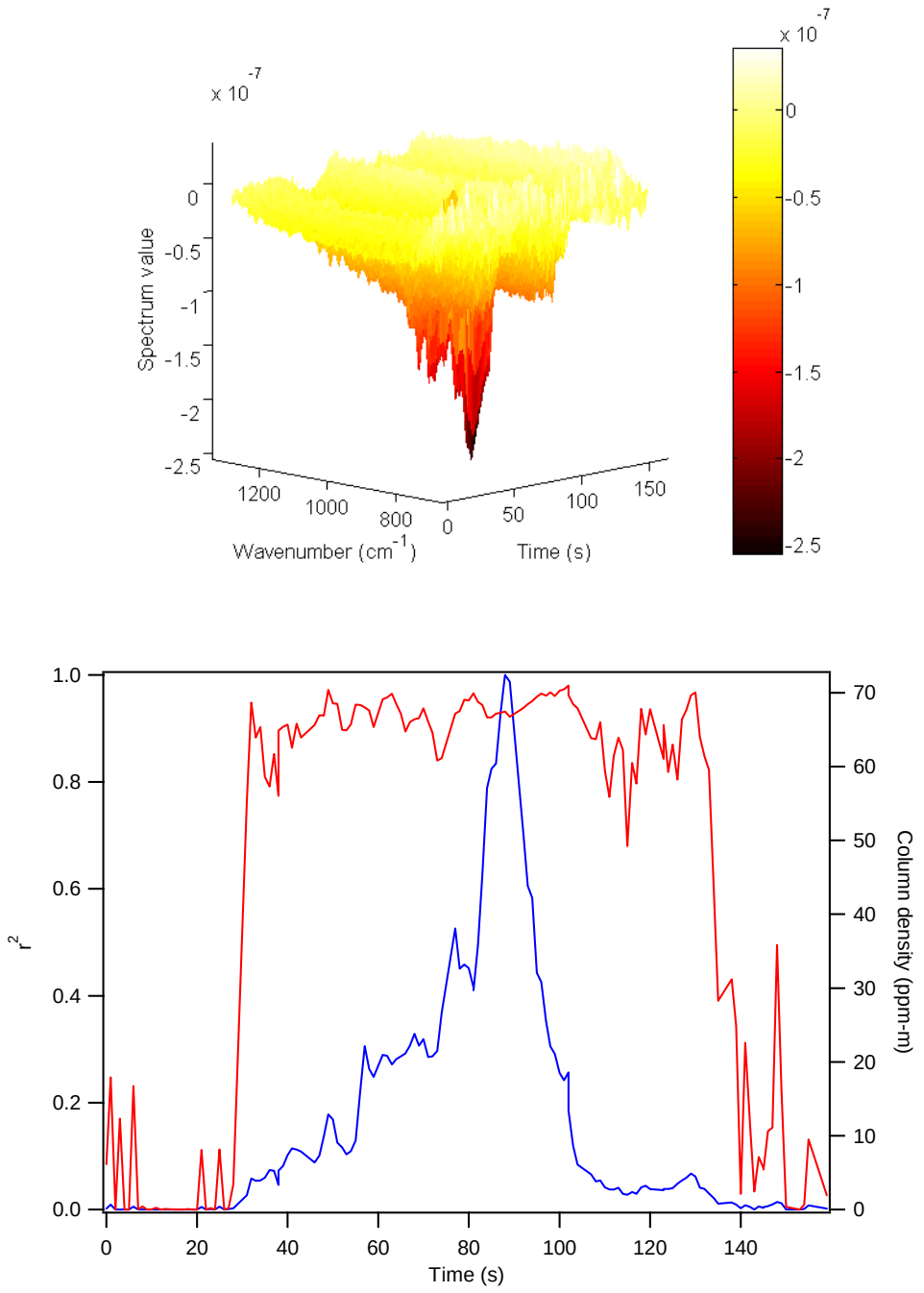


Figure 3. *3D Overlay plot of all radiance spectra (Watts/cm^2-sr-cm^{-1}) collected with CATSI sensor (top view), graph of the related CL (blue curve) and global r^2 (red curve) (lower graph) for a measurement performed on a plume generated with a flow rate of 100 L/min. Measurement performed at 15h16 (CATSI time) on natural background.*



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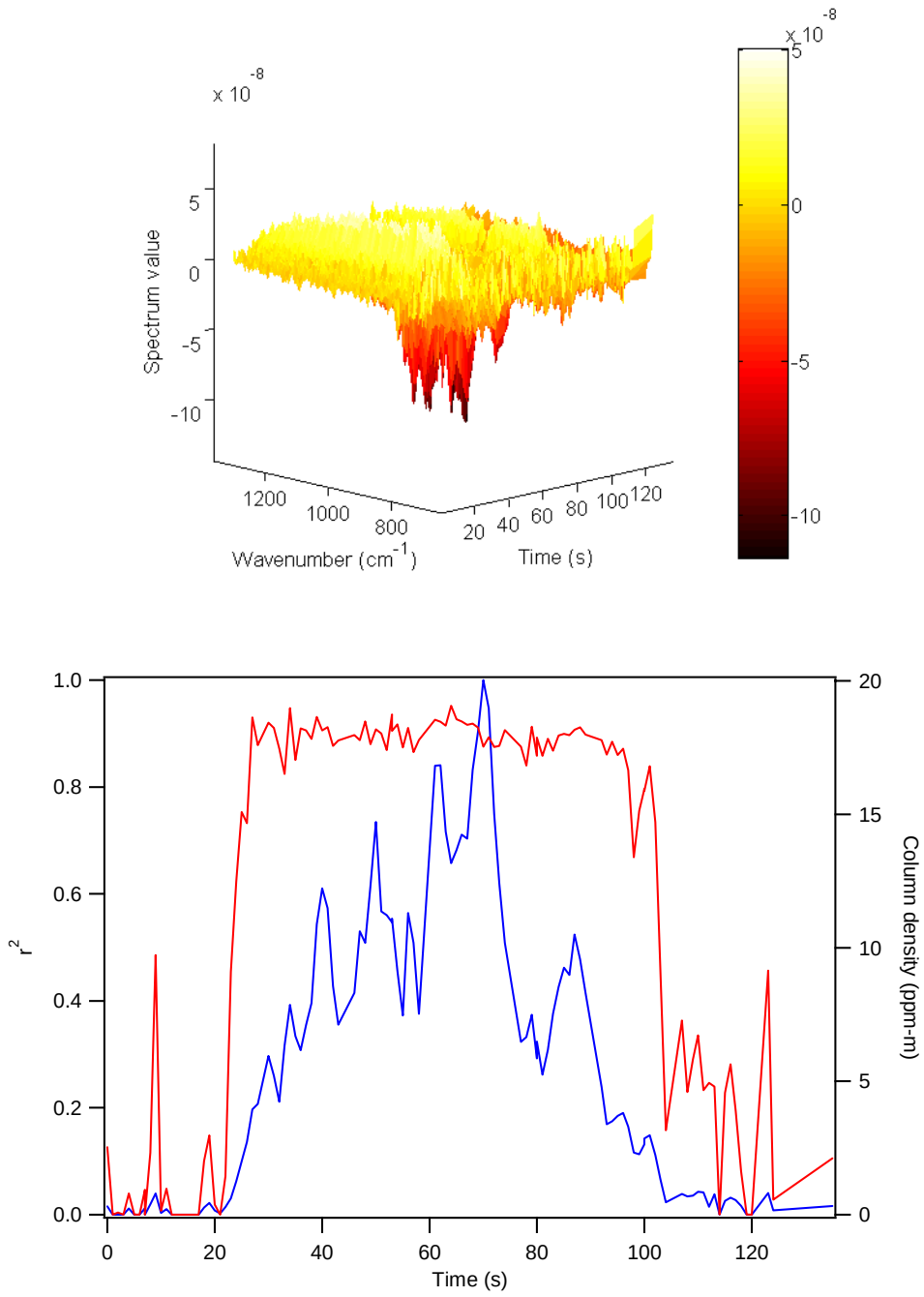

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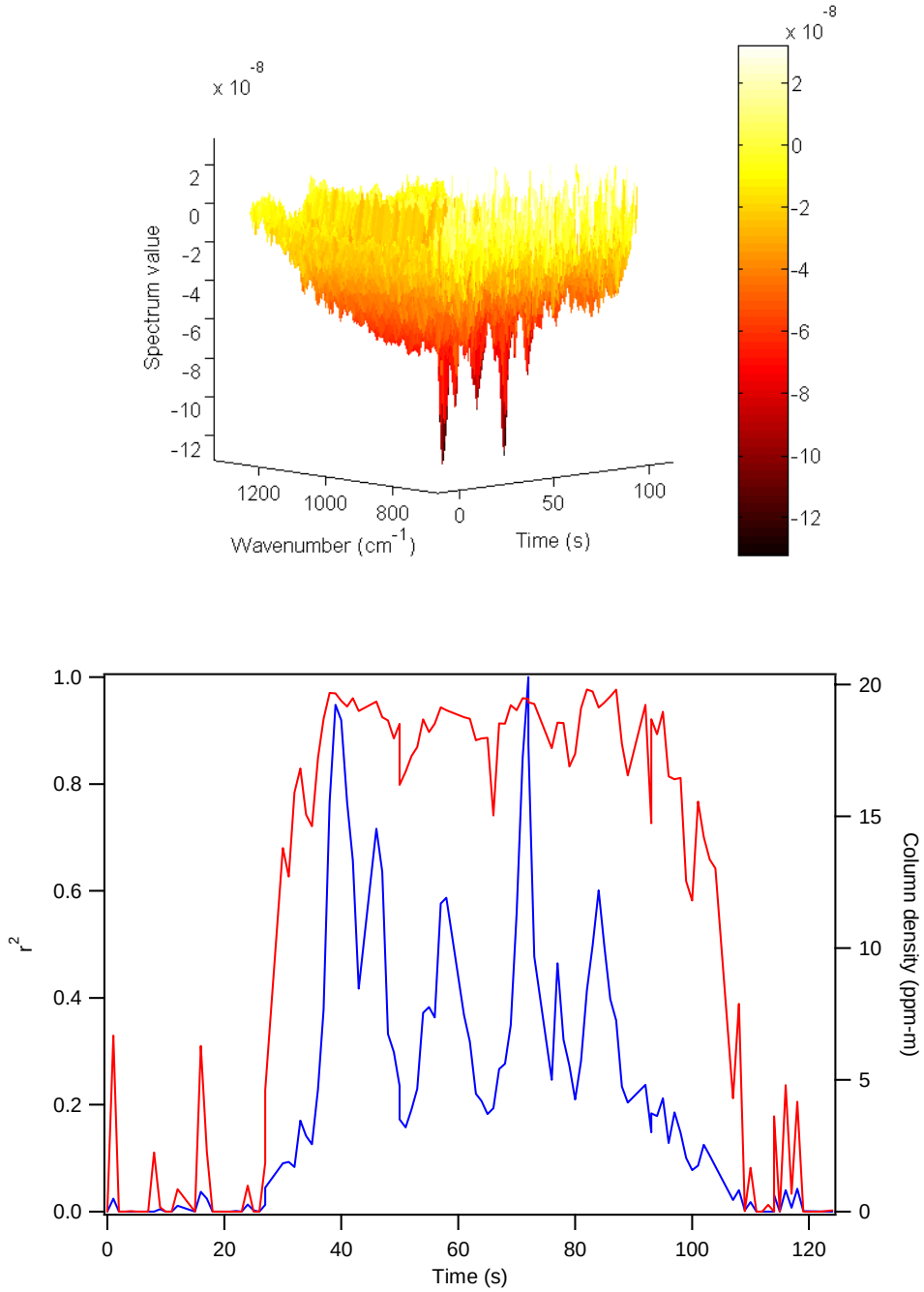

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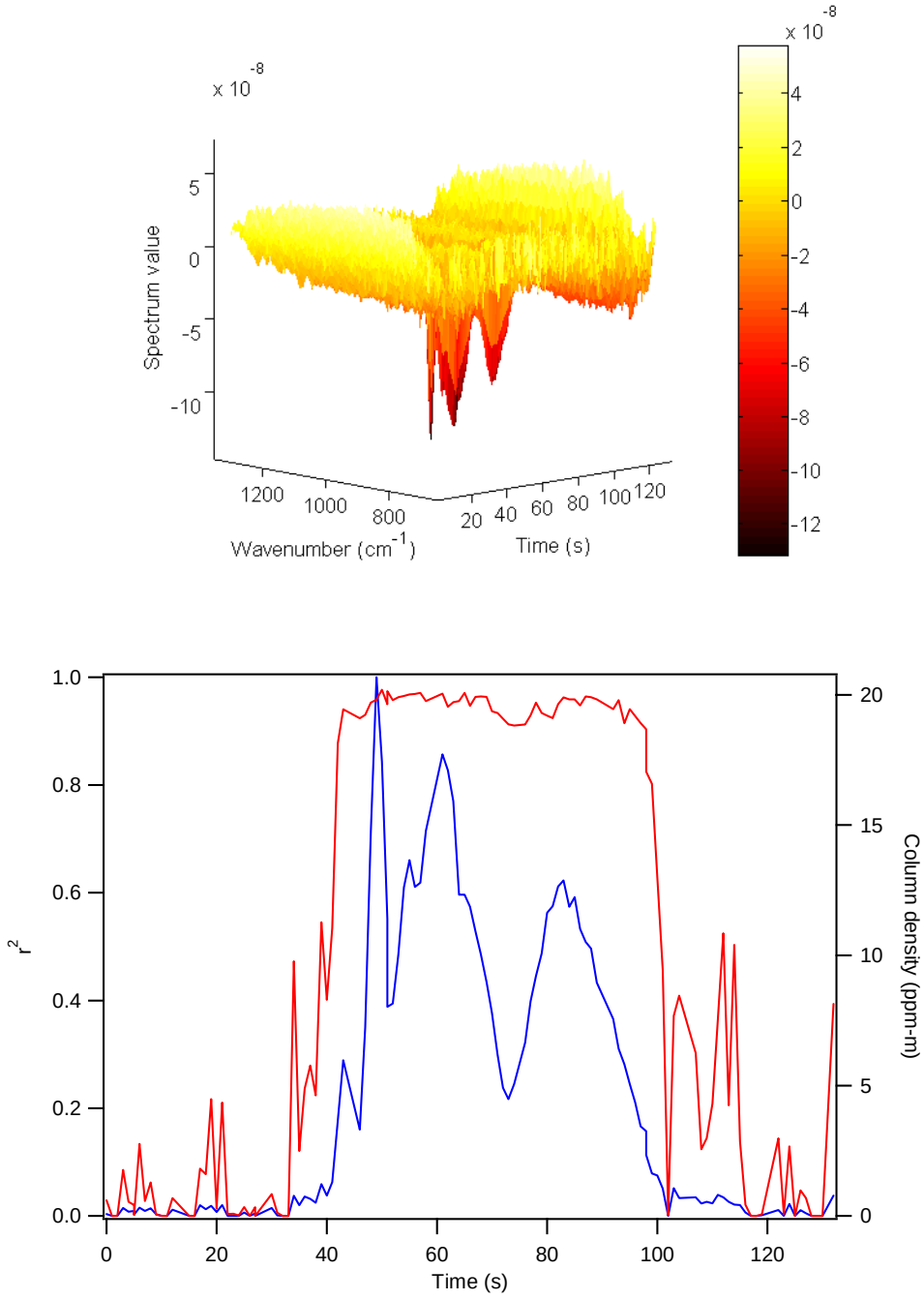

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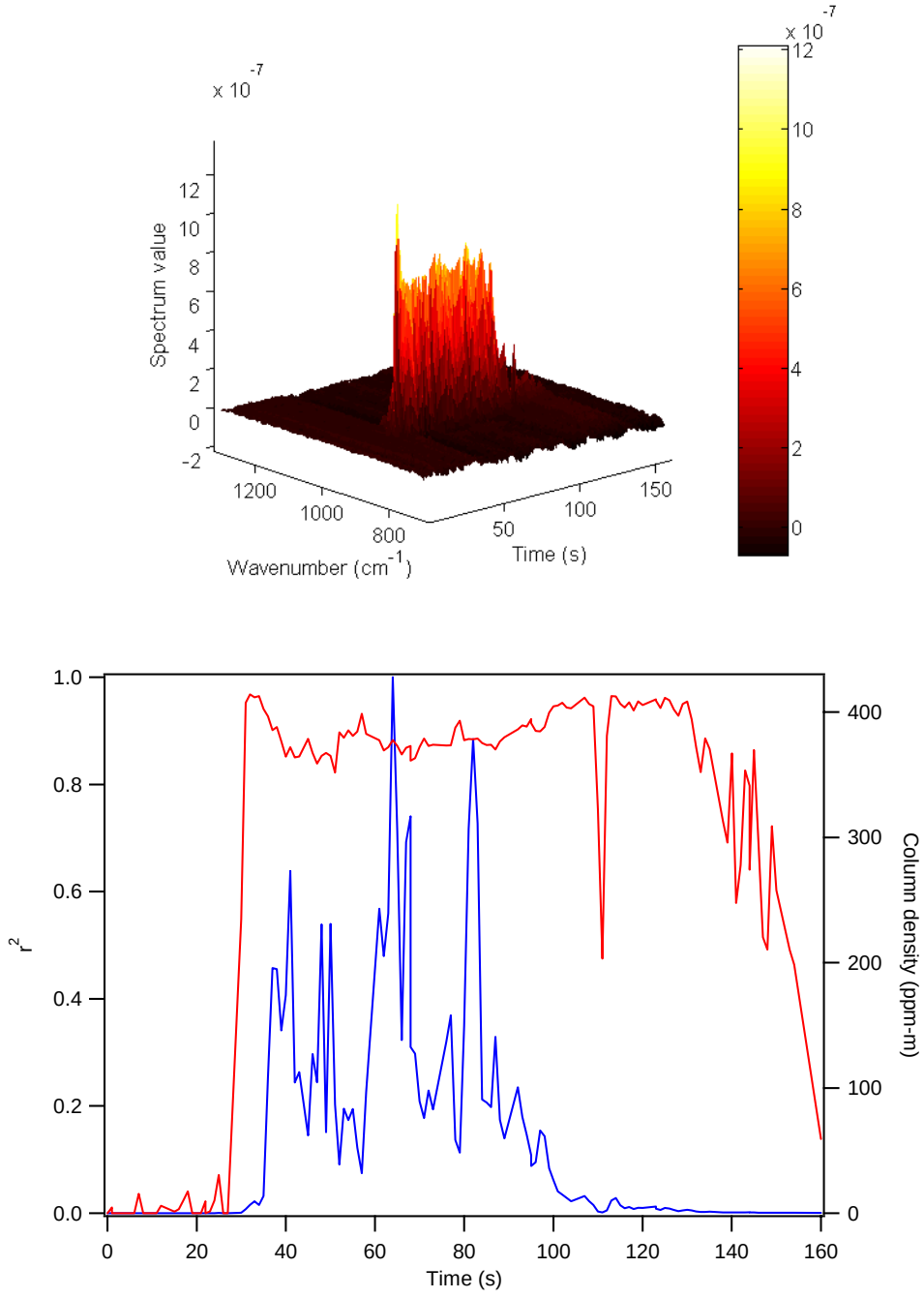

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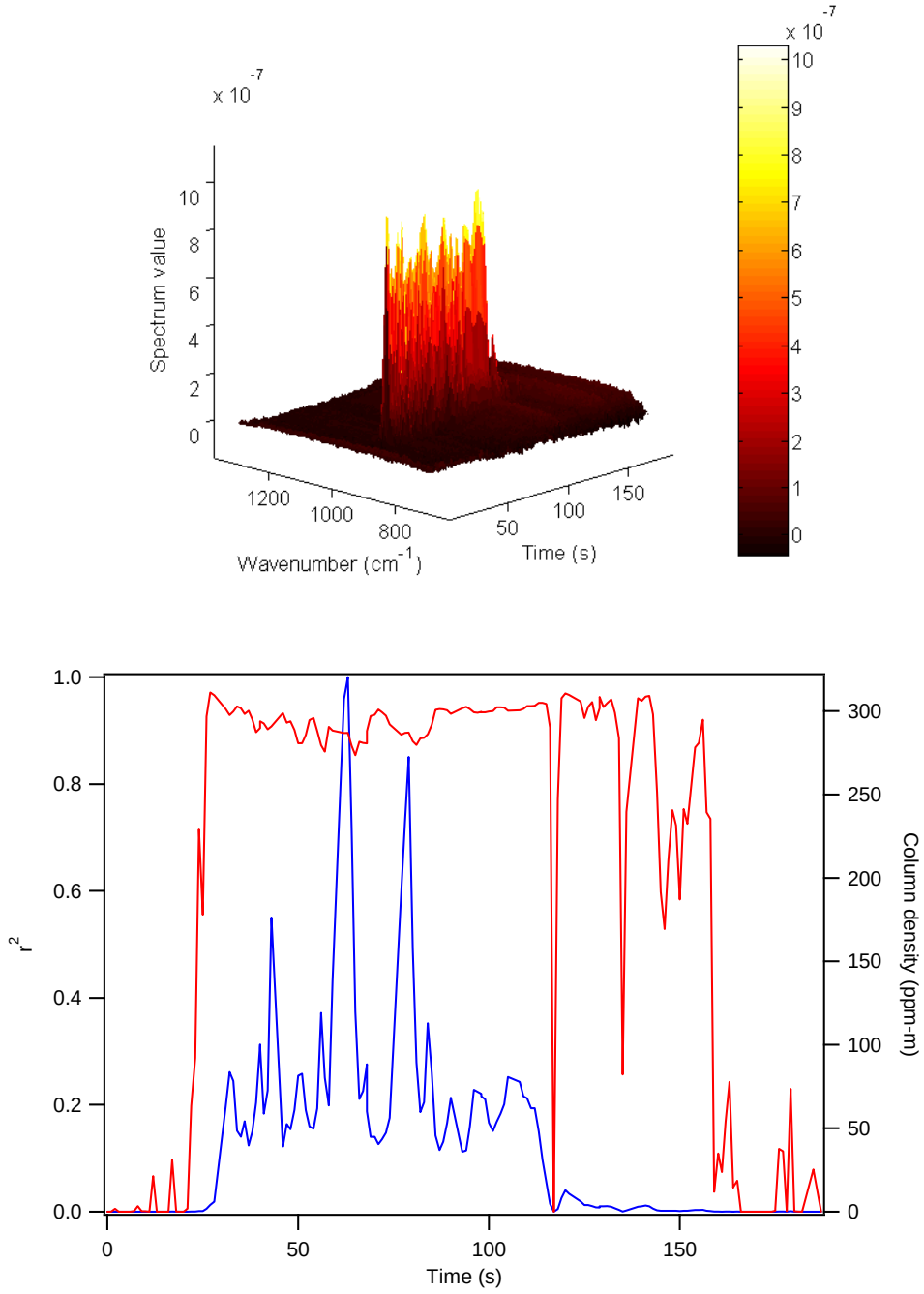

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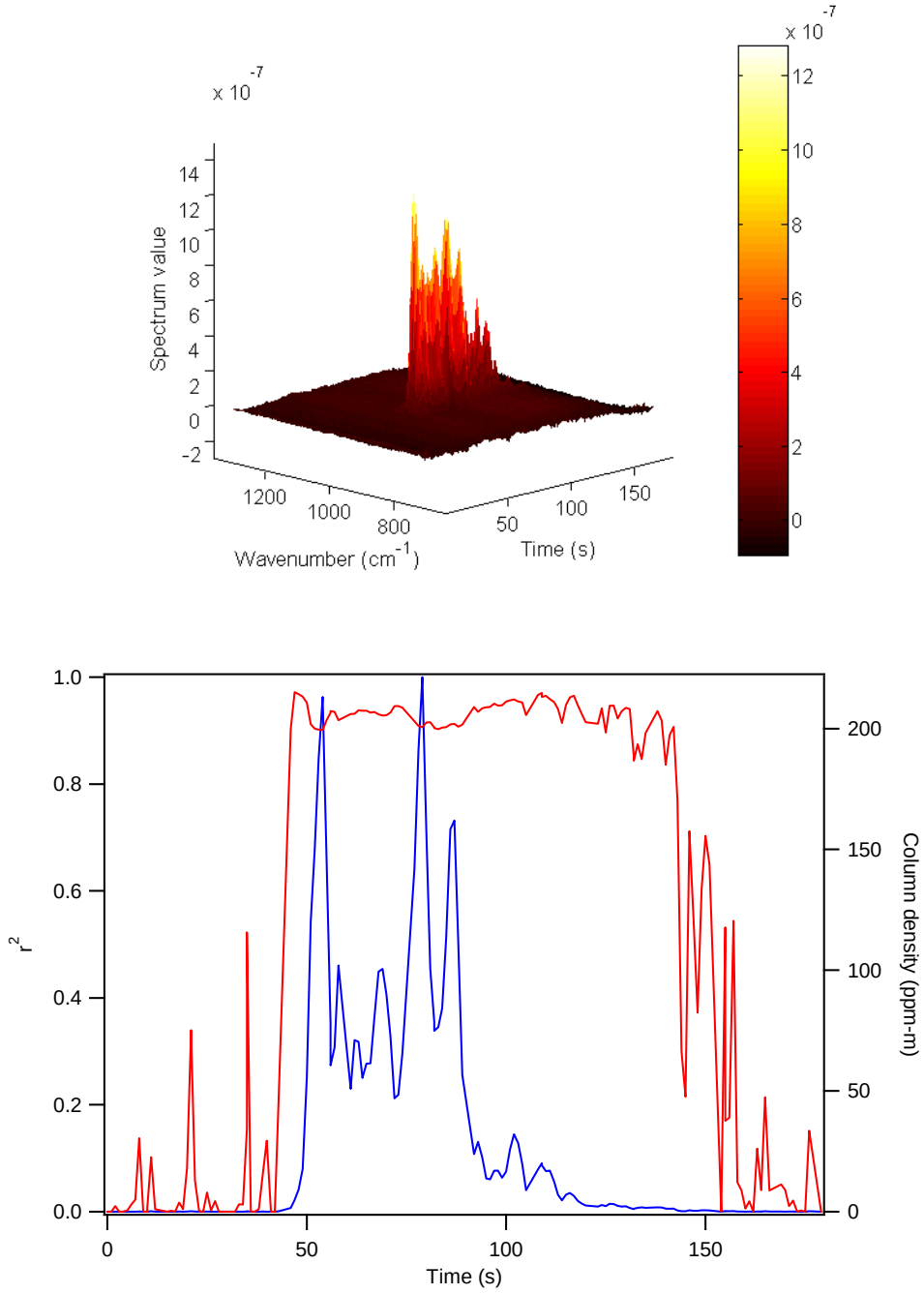

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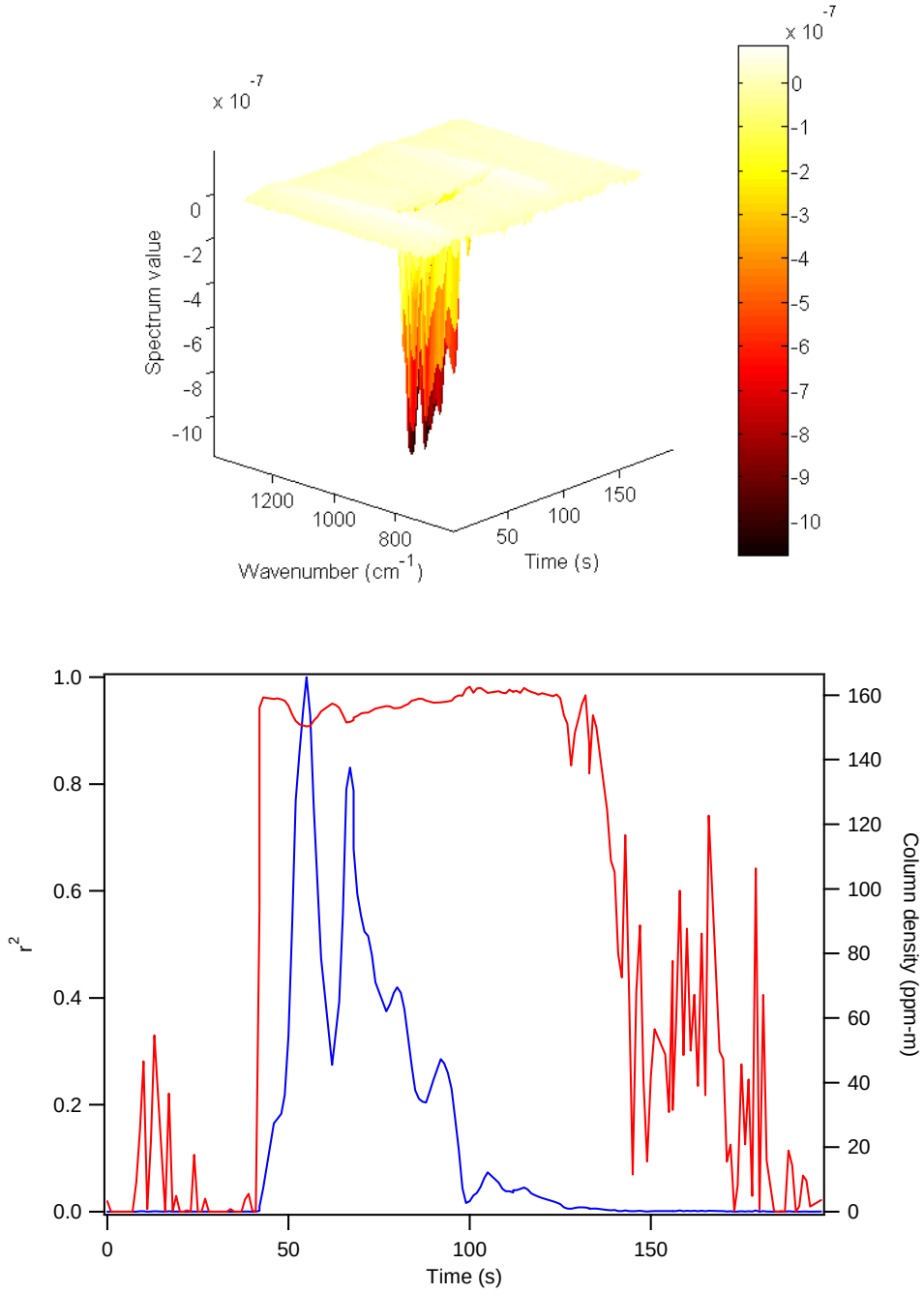

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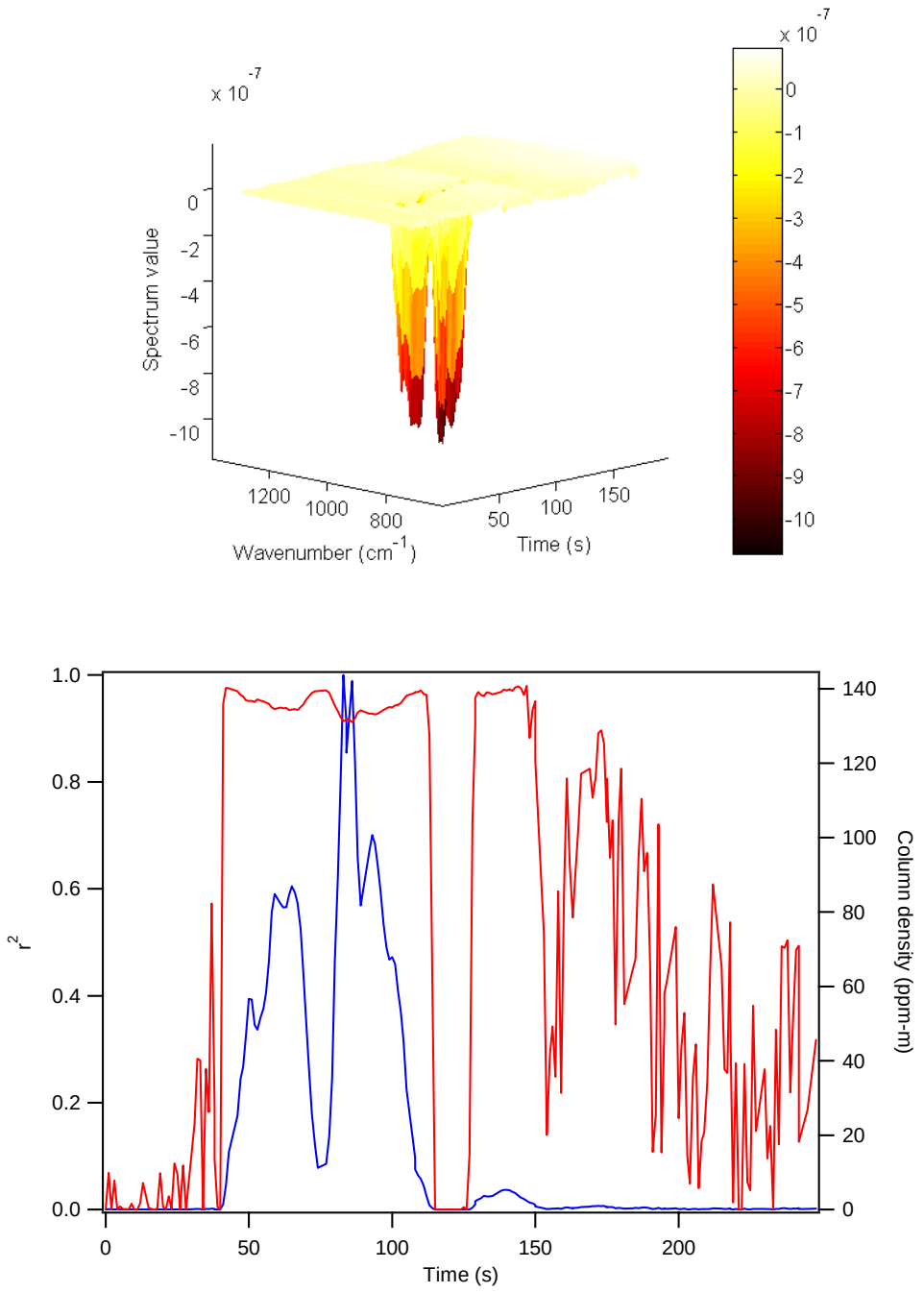
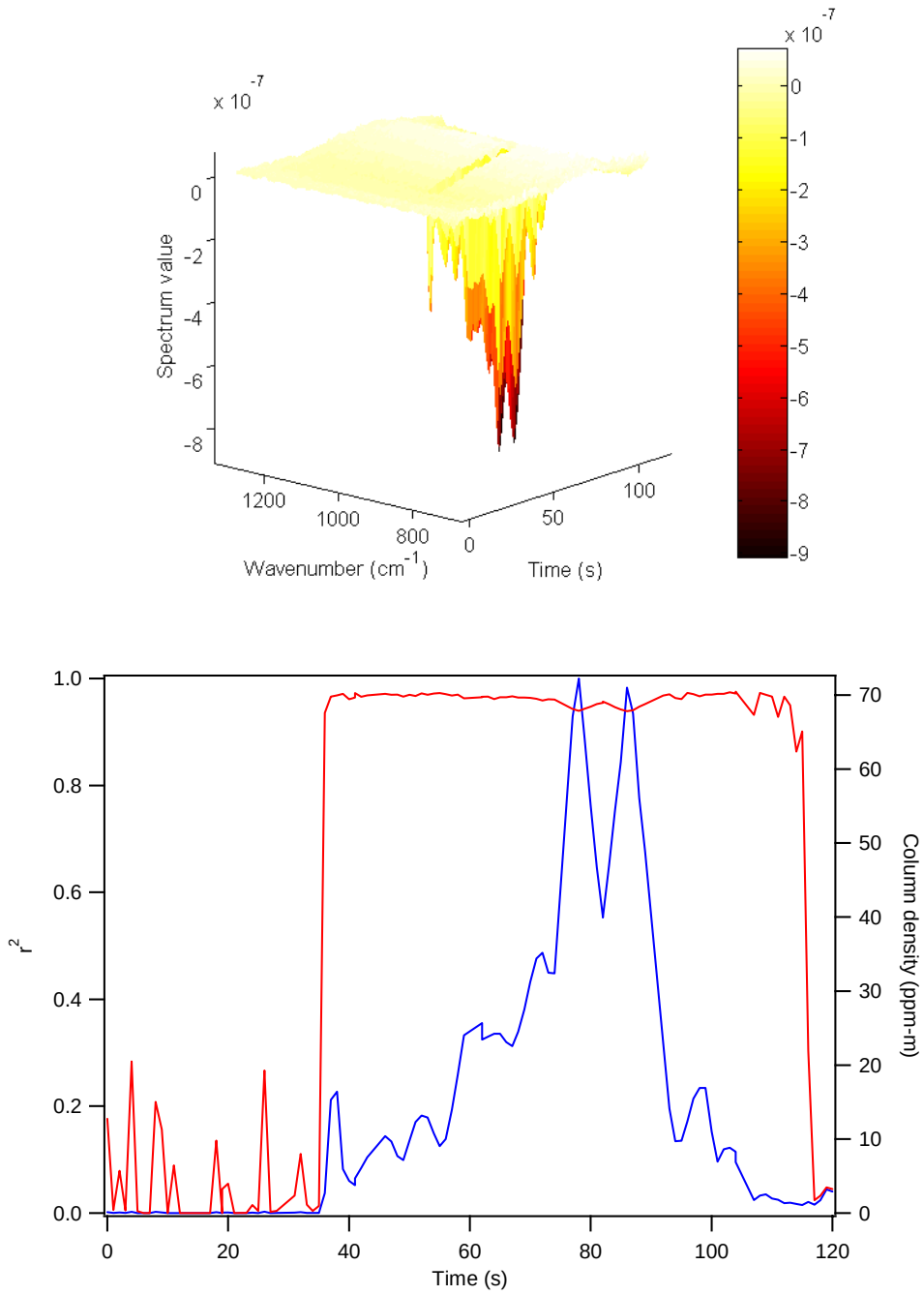


Figure 12. *3D Overlay plot of all radiance spectra (Watts/cm^2-sr-cm^{-1}) collected with CATSI sensor (top view), graph of the related CL (blue curve) and global r^2 (red curve) (lower graph) for a measurement performed on a plume generated with a flow rate of 50 L/min. Measurement performed at 16h20 (CATSI time) on absorbent background.*



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4. Conclusion

This external client report presented the spectral measurements performed with CATSI on September 29, 2004 for the release of SF_6 at 500 m. The measurements were obtained simultaneously with the Telops imaging sensor (FIRST) to validate the capability of the sensor and to acquire a data set for the development and validation of the detection, identification and quantification algorithms.

The Gasem algorithm was used to detect, identify and quantify the simulant (SF_6) plume released. The algorithm was setup to fit the column density (CL) and the spectral slope in function of the wavenumber (ΔTa). The column density was obtained for different background type and different simulant flow rate.

The column densities (CL) obtained for a released plume over natural backgrounds were consistent with values obtained in other field trials. The column densities obtained for the artificial backgrounds were inconsistent with the values obtained for natural backgrounds, being as high as an order of magnitude greater than expected. At the moment, there is no obvious explanation for this difference.

5. References

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This note reports the results of a data collection campaign performed with the CATSI sensor to measure the detectability, identification and column density of a SF_6 plume. The measurements were made simultaneously with the Telops imaging sensor known as FIRST. The objective of this measurement campaign was to provide a validation of the Telops FIRST spectrometer. Measurements were taken at the 500 m open-air corridor at DRDC Valcartier on September 29, 2004.

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Standoff detection, CATSI, Fourier-transform infrared spectrometer, SF6

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